W9132T-04-C-0016

William Shisler and Govindasamy Tamizhmani, PhD
Photovoltaic Testing Laboratory
Arizona State University's Polytechnic campus

Midpoint Project Description Report

Proton Exchange Membrane (PEM) Fuel Cell Demonstration
Of Domestically Produced PEM Fuel Cells in Military Facilities

US Army Corps of Engineers
Engineer Research and Development Center
Construction Engineering Research Laboratory
Broad Agency Announcement CERL-BAA-FY03

Silvestre S. Herrera US Army Reserve Center, Mesa, Arizona

7/21/2006

Executive Summary

Two Proton Exchange Membrane (PEM) fuel cell systems from different manufacturers (Plug Power and IdaTech) are used in this demonstration project at the Sergeant Silvestre S. Herrera United States Army Reserve Center in Mesa, Arizona, Building 602. The electrical power output capacity of the Plug Power system is rated at 5 kW_{AC}, with the IdaTech system rated at 4.5 kW_{AC}. However, the units are running at 2.5 kW_{AC} and 2 kW_{AC}, respectively, for the duration of the demonstration. Both fuel cells use natural gas as their fuel and are grid-connected. Both units can provide combined heat and power (CHP), but the thermal energy use is not considered in this demonstration project.

Of interest in this demonstration is the ability of two fuel cells, made by different manufacturers, to operate well side-by-side during the required system demonstration time. Contract award for this demonstration is $429,907. The local host site individual is Mr. James B. Cresto, Project Manager, 63rd RSC Engineer, whose e-mail address is James.Cresto.TADPGS@usarc-emh2.army.mil. His cell phone is 480-650-6164.

Table of Contents

Table of Figures

List of Tables

Proposal – Proton Exchange Membrane (PEM) Fuel Cell Demonstration of Domestically Produced Residential PEM Fuel Cells in Military Facilities

1.0 Descriptive Title

A one-year demonstration project utilizing two different fuel cell units at the US Army's Silvestre Herrera Reserve Center, Mesa, Arizona.

2.0 Name, Address and Related Company Information

Photovoltaic Testing Laboratory, Arizona State University Polytechnic (formerly ASU East)
7349 E. Unity Avenue, Mesa, Arizona 85212
480-727-1220
DUNS number: 943360412
CAGE code: 4B293
Tax Payer ID number:

The Photovoltaic Testing Laboratory is a part of Arizona State University's Polytechnic campus, located at the old Williams Air Force Base, Mesa, Arizona. It functions to provide qualification testing services to manufacturers in the photovoltaic industry, and also serves as a third party testing laboratory for Underwriters Laboratories. It engages in academic activities by providing alternate energy classes to graduate and undergraduate students at the university. Included in these courses is instruction in the theory and practical applications of fuel cells. Practical, hands-on training is provided. The demonstration program at the Sylvestre Herrera Reserve Center will give further opportunities for student involvement.

3.0 Production Capability of the Manufacturer

Product from two fuel cell manufacturers are used in this demonstration program.

First fuel cell supplier:
Plug Power of 968 Albany Shaker Road, Latham, New York 12110
Contact information:
Vincent Cassala
E-mail: vincent_cassala@plugpower.com
Ph : 518-782-7700 X 1228

Second fuel cell system supplier:
Ida Tech, 63160 Britta Street, Bend, Oregon 97701
Contact information:
Tucker Ruberti
E-mail: truberti@idatech.com
Ph: 541-322-1046

4.0 Principal Investigator(s)

Govindasamy Tamizhmani, Ph.D.
Director, Photovoltaic Testing Laboratory
Arizona State University East
7349 E. Unity Avenue
Mesa, Arizona 85212
480-727-1220 Voice
775-314-6458 FAX
e-mail: manit@asu.edu

5.0 Authorized Negotiator(s)

Patricia Tennant
Sponsored Projects Officer
Arizona State University
480-727-1003

Dudley Sharp
Contracts Officer
Arizona State University
480-965-0273

6.0 Past Relevant Performance Information

(1) Project Title:
Establishment of a Fuel Cell Test Station

Project Experience:
A test station has been established to evaluate residential fuel cell systems at Arizona State University. This project involved three major tasks: Site development, Fuel cell system metering, and Fuel cell system installation. These major tasks included several subtasks including: construction of concrete pad; installation of awning, natural gas line, water line, wall mounted electrical service entrance along with protection units, LAN, internet based DAS, weather station, water and natural gas flow meters and electrical power meters; Mounting fuel cell system on the concrete pad, interconnection with local electrical grid and meeting the requirements of the local inspectors for gas and electrical connections.

Sponsor Name and Related information:
Salt River Project
P.O. Box 52025
Phoenix, Arizona 85072-2025
Point of contact: Ernie Palomino; E-mail: gepalomi@srpnet.com
Phone: 602-236-3014; Fax: 602-236-3407

Contract award date: 12/15/02 – 4/1/03

(2) Project Title:
Operation, On-Site Testing and Evaluation of a 5 kW Residential Fuel Cell System

Project Experience:
The fuel cell test station developed in the above project is now ready to be used to test a residential PEM, Proton Exchange Membrane, fuel cell system developed by a domestic manufacturer. This fuel cell system is commissioned and it is fully operational in both stand-alone and grid-connected modes. The primary objective of this project is to verify the manufacturer's performance claims and ratings. There are three major tasks involved in this project: Testing, Data Collection and Data Analysis. A slightly modified protocol of EPRI "Residential Fuel Cell

Testing Protocol for Grid-Connected Operation" is scheduled to be followed to test this fuel cell system. The tests include: Start-up operations, normal shut-down operation, steady state operation, transient load operation, part-load operation, sudden loss of load testing, short-circuit testing, overload testing and endurance testing.

Sponsor Name and Related information:
Electrical Power Research Institute (EPRI) and Salt River Project

Point of contact:
David Thimsen, EPRI
E-mail: dthimsen@epri.com; Phone: (651) 766-8826; Fax: (651) 765-6375
Ernie Palomino, Salt River Project
E-mail: gepalomi@srpnet.com; Phone: 602-236-3014; Fax: 602-236-3407

Contract award date: 01/01/03 – 07/31/04

(3) Project Title:
Fuel Cell Based Uninterruptible Power Supply (UPS) for Computers

Project Experience:
Arizona Public Service (APS), a local electric utility company, donated three fuel cell stacks, ranging from 250 W to 2000 W, for the research and development activities of Arizona State University. One of the H-Power PEM250 fuel cell stacks was chosen to power a single personal computer. After extensive investigation, appropriate dc-dc converter and dc-ac inverter were identified and integrated with the fuel cell stack and the computer. This UPS system is fully operational and it has been determined a full 2500 psi tank of hydrogen could support a single PC for about 40 hours.

Sponsor Name and Related information:
Arizona Public Service
Pinnacle West Corp.
P.O. Box 53490
Phoenix, Arizona 85072-3940

Point of contact:
Timothy McDonald; E-mail: Timothy.MCdonald@pinnaclewest.com
Phone: 602-250-3032

Contract:
No funds were provided but APS donated several fuel cell stacks to ASU to support the research and development efforts of ASU

7.0 Host Facility Information

The host site is the Sergeant Silvestre Herrera US Army Reserve Center, 6158 South Avery Street, Mesa, Arizona 85212. Point of contact at the 63rd Regional Readiness Command, Los Alamitos, California is Dr. Michael Siu, Chief, Facility Engineering. His telephone number is 562-795-2060; e-mail is: Michael.Siu@usarc-emh2.army.mil. Local contact is Mr. James B. Cresto, Project Manager, 63rd RCC Engineer. Mr. Cresto's e-mail address is James.Cresto.TADPGS@usarc-emh2.army.mil. His cell phone is 480-650-6164.

8.0 Fuel Cell Installation

8.1 System Site

The Sylvestre S Herrera US Army Reserve Center is located on the Arizona State University Polytechnic/Williams Gateway campus, at N33°18′ latitude, W111°39′ longitude, about 1,380 feet above sea level, and less than ¼-mile west of the Photovoltaic Testing Laboratory. It is a hot and dry climate, where the average high temperature in July is 104°F and the average low in January is 39°F, with an annual precipitation less than 10 inches.

In early 2005, most of the Reserve Center activity was moved into a newly constructed building directly south of ASU-PTL. However, the fuel cell site is located at the old Reserve Center building. Figure 8-1 shows a drawing of the old Reserve Center site layout.

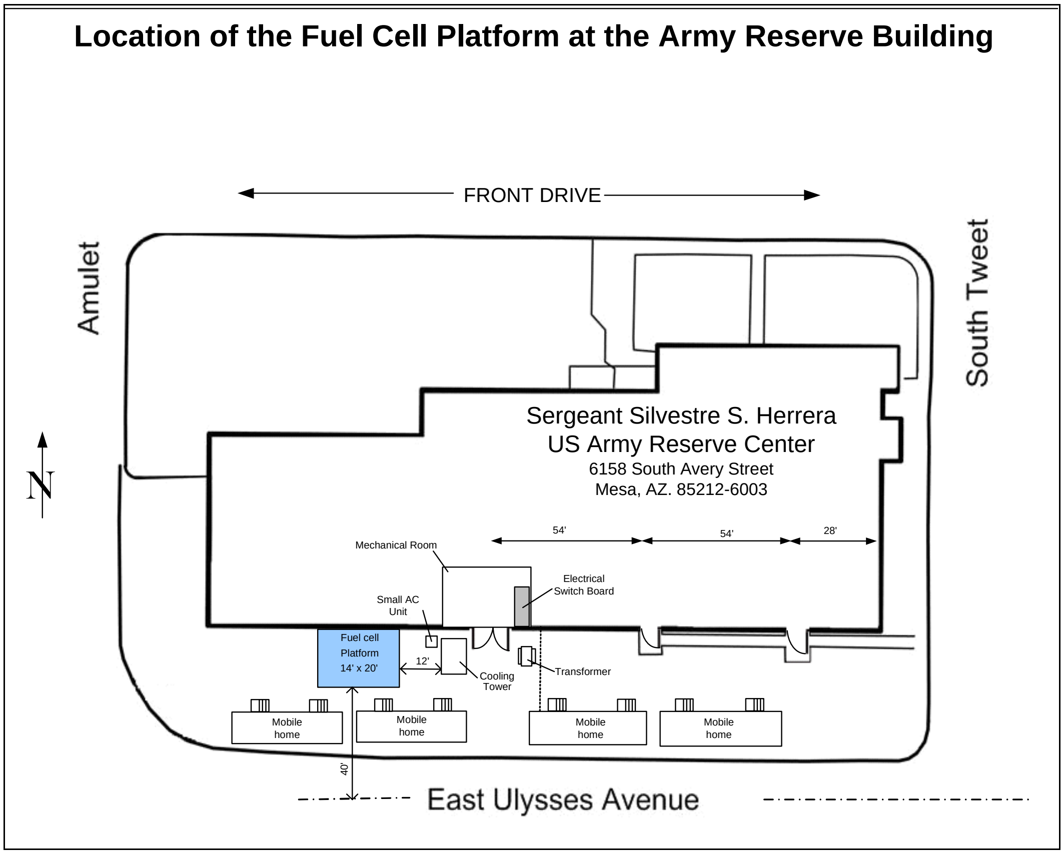


Figure 8-1: Site layout for fuel cell system installation.

The Plug Power and IdaTech system site requirements are listed in Table 8-1.

System	IdaTech nGen5	Plug Power Gensys
Gas pressure	3 to 11 INWC	4 to 11 INWC
Gas flow	< 40 SLPM	50 SLPM
Water pressure	Not specified	40 to 120 psig
Water hardness	Not specified	<15 grains per gallon
Electric	208 Vac, 60Hz, 2Φ	120 Vac, 60 Hz, 1Φ
Typical Environment	Indoor – 36°F to 104°F	Outdoor – 0 to 104°F, 10 to 90% RH

Table 8-1: System site requirements.

In late 2004, an awning and fence were constructed on the south side of the old Sylvestre S. Herrera US Army Reserve Center building. The awning was built to provide some shading to protect against the extreme summer days in Mesa, AZ, which can exceed temperatures of 110°F. The fence is a simple deterrent for curious passers-by. The construction of the awning was contracted outside and was completed in September 2004. The fence was installed by ASU-PTL on September 17, 2004. Figure 8-2 shows the awning and fence in place before the systems were installed.

Figure 8-2: Awning and fence built and ready for fuel cell systems.

8.2 Platforms

Prior to installation, ASU-PTL constructed two mobile platforms, each with compatible hook-ups for natural gas, water, and electrical delivery. Each fuel cell system was placed on its own platform. The Plug Power fuel cell system arrived at ASU-PTL on August 2, 2004, and was secured to its platform on August 13, 2004. The IdaTech unit arrived at ASU-PTL and was secured to its platform on November 30, 2004.

Each platform is equipped with a deionization (DI) water treatment plant (provided by each respective fuel cell manufacturer), a data acquisition system, a large plug for the AC electrical connection, gas and water flow meters and transducers, gas and water pressure meters, and adjustable legs for site balancing. A mockup drawing of the platforms is shown in Figure 8-3.

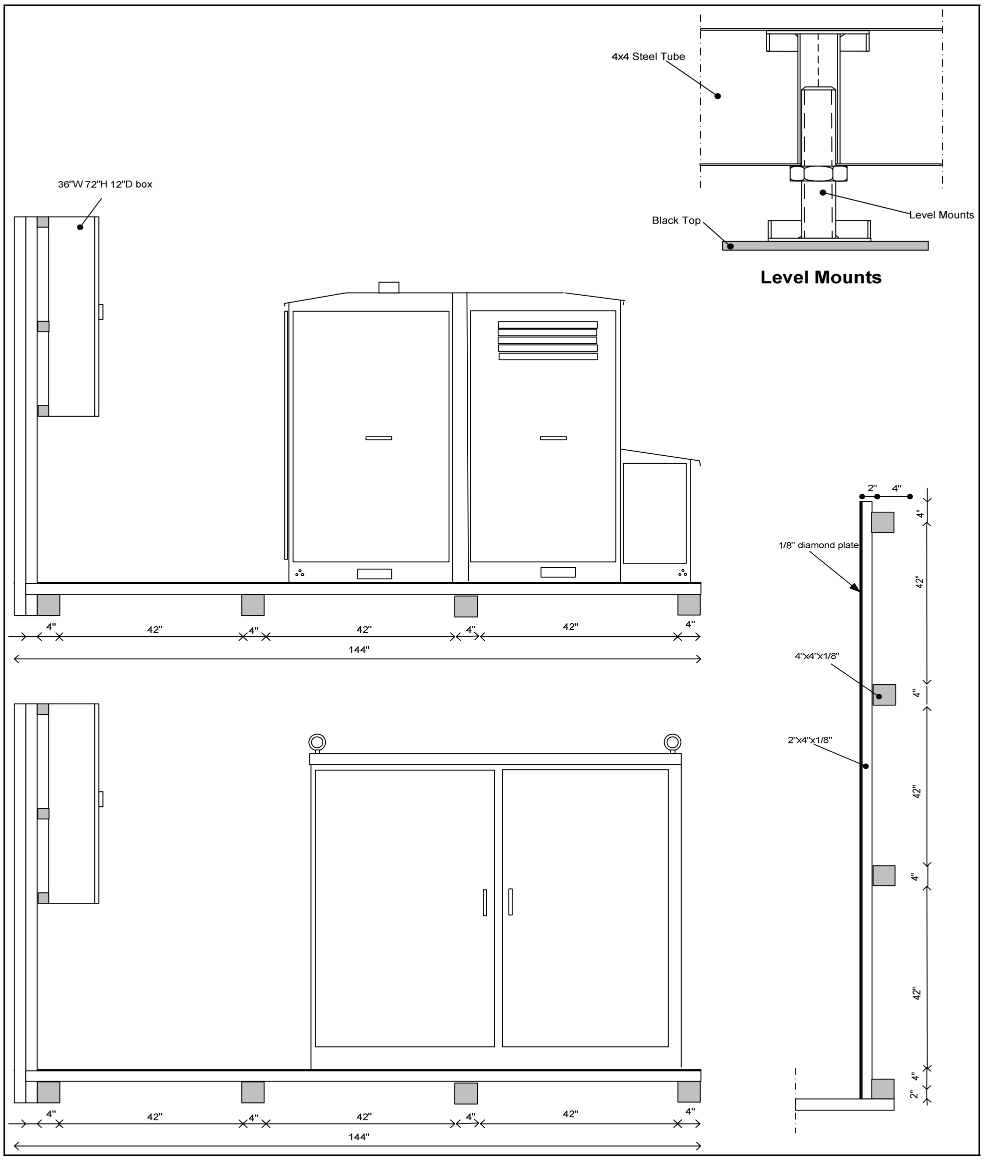


Figure 8-3: Fuel cell platform mock-up drawings – Plug Power on top, IdaTech on the bottom.

The idea for the platforms is educational in nature. After the completion of the CERL system demonstration, the platforms and fuel cell systems will be transported back to the lab to serve as a teaching tool in the university's alternative energy program.

A snapshot of the platform construction is shown in Figure 8-4. Figures 8-5 and 8-6 show the IdaTech and Plug Power systems mounted on the platforms at the lab, respectively.

Figure 8-4: Fuel cell platform construction.

Figure 8-5: The IdaTech system on its platform at the lab. A nitrogen bottle is hooked up for a gas pressure/leak check.


Figure 8-6: The Plug Power system installed on a test platform.


Figure 8-7: Beginning to move the Plug Power platform.

Once the fuel cells were placed on the platforms, they were moved, via forklift (Figure 8-7), to the Sylvestre S Herrera US Army Reserve Center. The systems were then connected side-by-side, with the Plug Power unit being installed first. The lab purposely delayed installing both systems simultaneously. In case problems were encountered with the first system, the lab could work to solve them before the second one was in place.

Once the platforms were installed, the connections were made. The electrical connections were made by fitting two large outdoor plugs into a special 240Vac outlet, hard-wired by ASU-PTL prior to installation. The gas connections were form-fitted with black pipe, and the final water connection was welded. The total time to install each system was approximately 100 man hours. This included the copper pipe, electrical, and data acquisition requirements.

Figure 8-8: The two fuel cell systems installed at the US Army Reserve Center. The outdoor AC plug is projected.

8.3 Commissioning

Lab members attended a week-long course by Plug Power on Gensys 5C commissioning procedures. The fuel cell stack was installed at the lab by ASU-PTL. Two system coolant loops were filled – propylene glycol for general system heat transfer, and Therminol for the fuel cell stack. AC electrical connections were made, and the 48 Vdc battery bank was connected. The system was started up initially in Manual Mode by pressing the Start button on the unit. Once in Manual mode, the Plug Power Gensys could be commanded through its Service Interface Software on a local laptop computer, shown in Figure 8-9.

The IdaTech system was commissioned at the site by IdaTech engineers. ASU-PTL fuel cell staff was on hand for support. The commissioning included finishing the gas-line plumbing, installation of the inverter and fuel cell stack, and setting up remote communications through a firewall and satellite network. This commissioning time also served as operational training for ASU-PTL.

Figure 8-9: Dedicated laptop for data collection and commanding the Plug Power system. Plug Power's Service Interface Software is shown.

8.4 Operational Settings

The Plug Power Gensys has three basic power dispatch settings: 2.5 kW, 4 kW, and 5 kW. Based on previous experience with a Plug power Gensys, the lab decided to run the demonstration exclusively at the 2.5 kW setting. It was concluded that the unit would run more reliably, for a longer period of time, at the 2.5 kW setting in comparison to 4 kW and 5 kW.

The IdaTech system can be set at multiple power dispatch settings, ranging from about 500W to 4.5 kW, based on the percentage of capacity chosen. The power dispatch for IdaTech is set remotely by IdaTech engineers. For the purpose of this demonstration, ASU-PTL requested a power dispatch setting of 2 kW for the IdaTech system (about 44% of its electrical capacity).

Both systems are considered as combined heat and power (CHP) plants, where the customer can make use of the waste heat generated as a hot water source or space heating. The lab chose not to make use of the CHP capabilities of either system during the demonstration. The systems are grid-connected without additional load.

8.5 Estimated Energy Savings

ASU-PTL does not expect a net gain on energy expenditures during this demonstration. Table 8-2 shows the net energy production, consumption, and energy costs expected during the demonstration period, based on Southwest Gas natural gas energy tariffs and the SRP small power plant buy back plan in early 2005.

May to October 2005 – summer rates (electric - $0.0814/kWh, gas - $0.81559/Therm)
November 2005 to April 2006 – winter rates (electric - $0.0640/kWh, gas - $0.81559/Therm)

	IdaTech nGen5	Plug Power Gensys
Output at 90% Availability	15,728 kWh	19,710 kWh
Production -- SAVINGS	$1,145	$1,434
Manufacturer reported efficiency	25%	26%
Input at 90% Availability	2,152 Therms	2,586 Therms
Consumption -- COST	$1,755	$2,109
Overall SAVINGS	-$610	-$675

Table 8-2: Estimated annual net energy savings of the two fuel cell systems at start of project.

8.6 Interconnection agreement

The installation and running of the two systems at the Army Reserve Center were a long time in coming after the project was accepted by CERL. Specifically, there were legal issues regarding liability between Arizona State University and Salt River Project, the local electrical utility. ASU-PTL originally planned to have both systems installed and running by December 2004. However, because of a delayed electrical interconnection agreement, the first of the two systems was not commissioned until late March 2005.

9.0 Electrical System

The Plug Power Gensys 5C and the IdaTech nGen5 required different electrical configurations. The Gensys delivers 120 Vac, 60Hz 1-phase to the local grid. The nGen5 system is set to deliver 240 Vac, 60 Hz, 2-phase. In order to support each configuration, ASU-PTL ran 3-phase, 240 Vac, 50A service from the local grid transfer disconnect and distribution switch board. A one-line electrical diagram is shown in Figure 9-1.

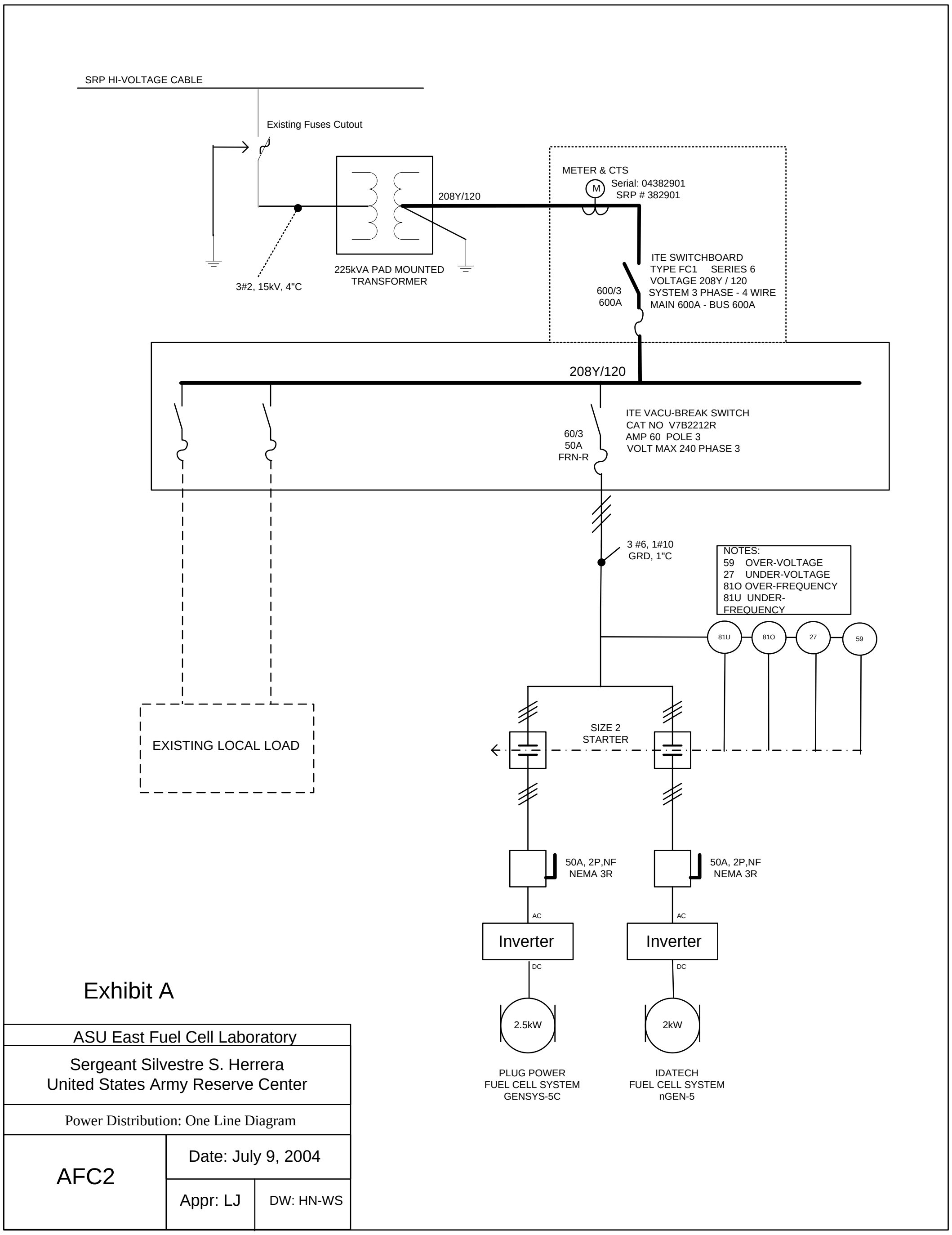


Figure 9-1: Fuel cell site electrical one-line diagram.

Both systems were connected only to the local electrical grid. No subsequent critical loads were connected. The systems were set to operate independently of one another, and in parallel to the grid. No loads inside the Reserve Center building would be affected by the operation of the fuel cell systems.

The IdaTech system requires a continuous grid-presence to operate. If the local grid goes off-line, the IdaTech system must be restarted manually (locally) or remotely by IdaTech engineers. The Plug Power system has a 48 Vdc battery, which can serve as a load temporarily, so the fuel cell stack can continue to supply low current DC power until the electric grid comes back on-line. The Plug Power inverter continues to survey the electric grid until it sees a 5-minute, uninterrupted, clean grid signal. The battery is also used to provide initial startup power until all stages of the system reformer reach operating temperatures. The inverters for both systems are UL1741 Listed for safety.

For redundancy, the local electric utility – Salt River Project – required additional grid voltage and frequency protection. ASU-PTL installed a solenoid, which was tripped by either a grid under/over voltage or under/over frequency protection relay.

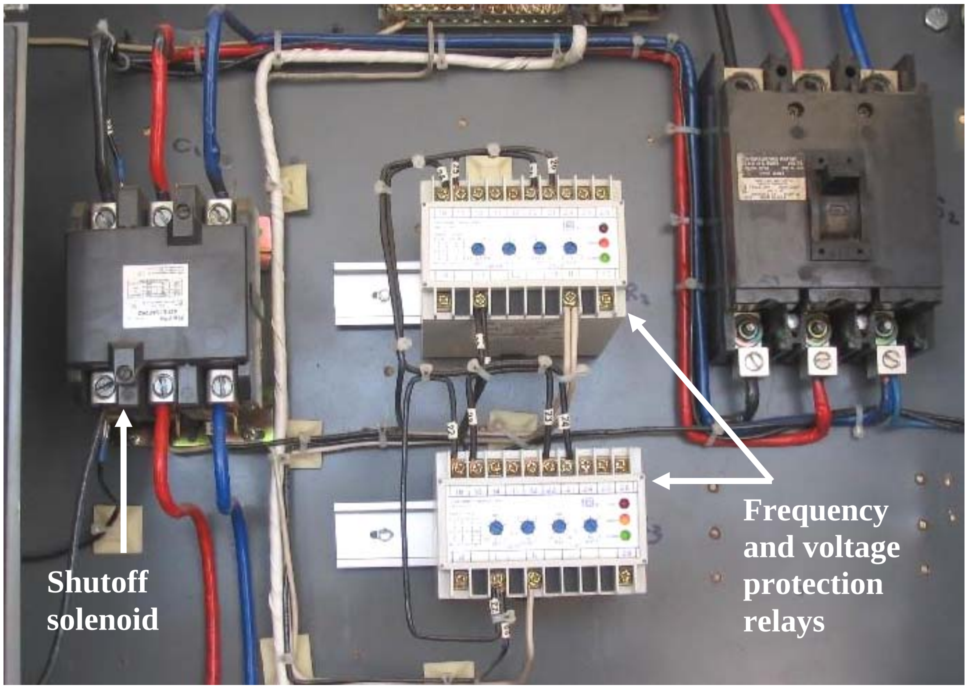


Figure 9-2: Additional grid protection as required by the local electric utility.

There are three physical disconnects external to each system, disregarding the voltage and frequency protection contact relay. The main utility disconnect (50A, fused) is located inside the Army Reserve building utility room. The second disconnect (50A, fused) is located just outside the fence line of the demonstration units. Each system has a third disconnect on its own platform.

10.0 Thermal Recovery System

There is not much need for additional hot water in the Mesa, AZ climate. Therefore, neither system was used for combined heat and power (CHP) applications.

11.0 Data Acquisition System

The following parameters were measured and submitted in a monthly report:

- ☐ Ambient temperature
- ☐ Natural gas consumption
- ☐ Electrical energy supplied to grid
- ☐ Other temperatures/parameters deemed appropriate

Each of the above parameters was set to be measured externally to each fuel cell system. In this way, ASU-PTL will take a "black box" approach in observing each of the systems. Each system will use natural gas as an input fuel, and produce AC grid electricity to the local electric grid. Based on the "black box" approach, it does not matter to ASU-PTL what happens in between – within the processes of the system. The only concerns for the consumer are how much energy is consumed by the system versus how much energy is produced, regardless of manufacturer claims or reports.

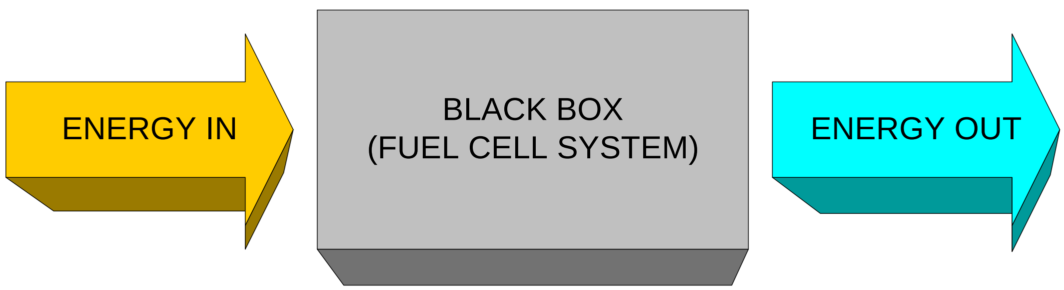


Figure 11-1: The "black box" approach for monitoring energy consumption and production.

In addition to the external system measurements, each manufacturer should supply its own internal system data. The Plug Power internal data was collected locally by ASU-PTL, while the IdaTech internal data was collected remotely by IdaTech engineers.

The ASU-PTL external data was set up for collection in ten-minute intervals using Campbell Scientific CR10X data acquisition systems – one for each system. ASU-PTL personnel chose the CR10X because of its durability and reliability, as well as a familiarity of the system.

Initially, the lab tried to set up a remote data connection, using an ISDN line for Internet service. Because of trouble with telephone communication on the campus and university firewalls, ASU-PTL decided to collect its data locally with an on-site laptop computer.

The Plug Power CR10X was connected to the laptop via a Campbell Scientific NL100 Ethernet adapter. The IdaTech CR10X was connected through an RF400 – a 900MHz radio transmitter/receiver specifically designed for CR10X use in remote areas. The CR10X can connect to the NL100 through the RF400, allowing its data to be downloaded to the laptop. PC208W software, also from Campbell Scientific, was set up to retrieve the data at a local PC, where it will be stored in .CSV files and translated to an Excel spreadsheet.

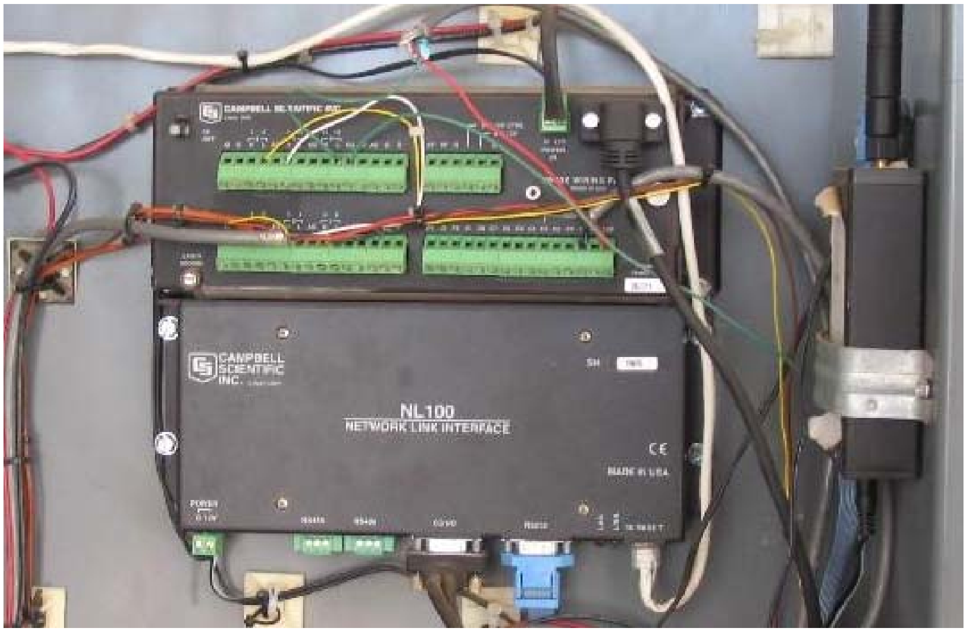


Figure 11-2: The ASU-PTL data acquisition system.

The Plug Power Gensys system has an onboard computer that can collect data every minute when hooked up through a direct line to a PC, through an RS232 cable. The IdaTech unit was hooked directly to the Internet through a satellite communication link provided by IdaTech. A diagram of the data acquisition layout is shown in Appendix 3.

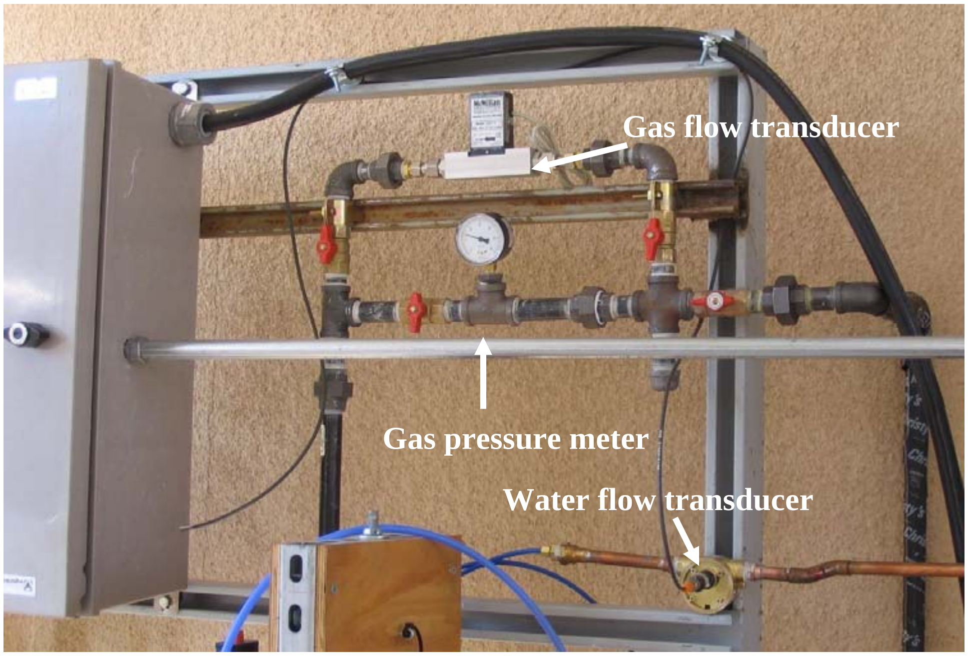


Figure 11-3: Monitoring system consumption.

Figure 11-4: AC power transducer used to measure the Plug Power Gensys. A similar model was used for IdaTech.

The entire ASU-PTL data acquisition system was powered by a battery, which was charged with a photovoltaic module. Because of this, the DAS remained independent of the electric grid and fuel cell systems. Data could continue to be collected whether or not the fuel cell systems were on-line or the grid was functional.

12.0 Fuel Supply System

There are three input fuels in each reformer fuel cell system:
1) natural gas;
2) water; and
3) air.

Oxygen is needed on the cathode side of a PEM fuel cell stack. The easiest way to get oxygen to the stack is by blowing ambient air across it. Because air is a free commodity, its consumption was not measured in this investigation.

Hydrogen is needed for the anode side of a PEM fuel cell. For each system, natural gas and deionized water were needed for the combustion process inside each systems high-temperature reformer. In a typical steam reformer, temperatures of over 700°C are reached to enable the methane portion of natural gas to be "cracked" into hydrogen (H_2) and carbon monoxide (CO). Because carbon monoxide is a poison to a PEM fuel cell, it must be "dumbed down" into carbon dioxide (CO_2), which will pass by the stack and out through the system exhaust. More stages are added to a steam reformer to minimize the amounts of CO that reach the stack. The vast quantity of sulfur in natural gas is separated prior to combustion through filtration in vessels called desulphurization beds.

$$CH_4 + H_2O \rightarrow 3H_2 + CO$$

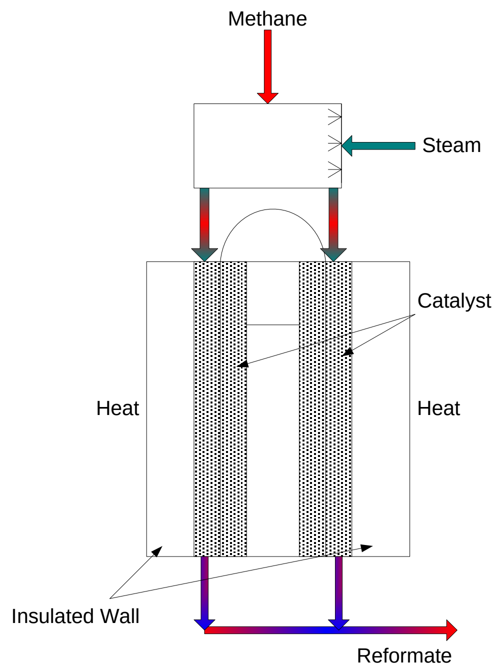


Figure 12-1: Drawing of a typical steam reformer, used to "crack" methane into hydrogen and carbon monoxide. The hydrogen can be used for a PEM fuel cell stack. The carbon monoxide must be mitigated in later reformer stages.

A water softener was installed to treat both systems' incoming city water. Each system employed a reverse osmosis and deionization treatment plant. A picture of the water softener and Plug Power water treatment plant is shown in Figure 12-2.

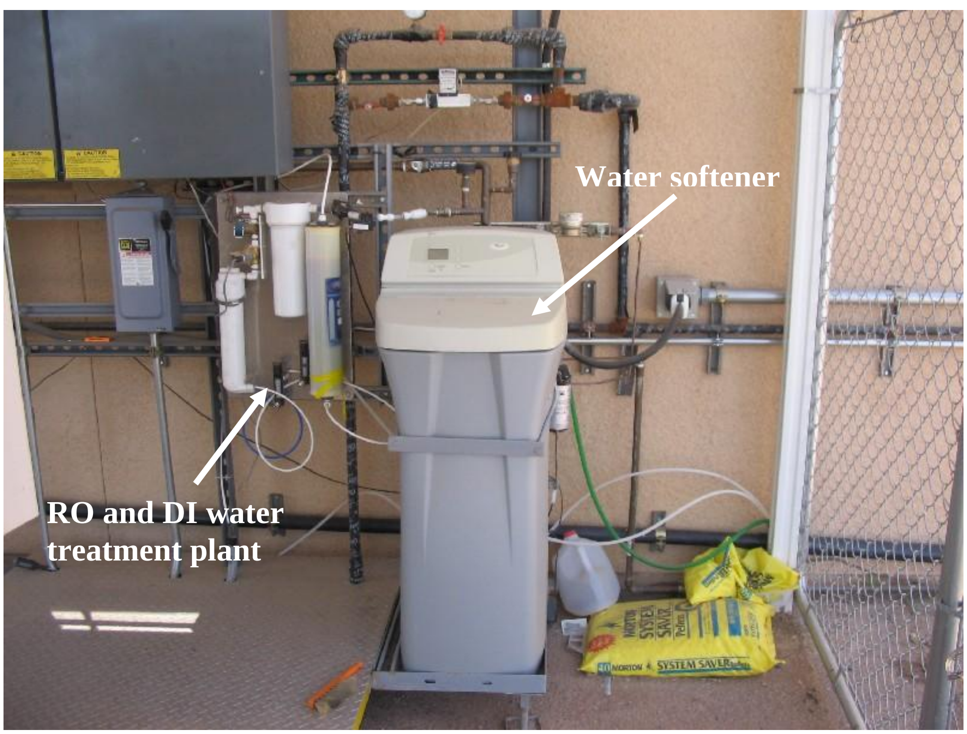


Figure 12-2: Water softener and Plug Power water treatment plant.

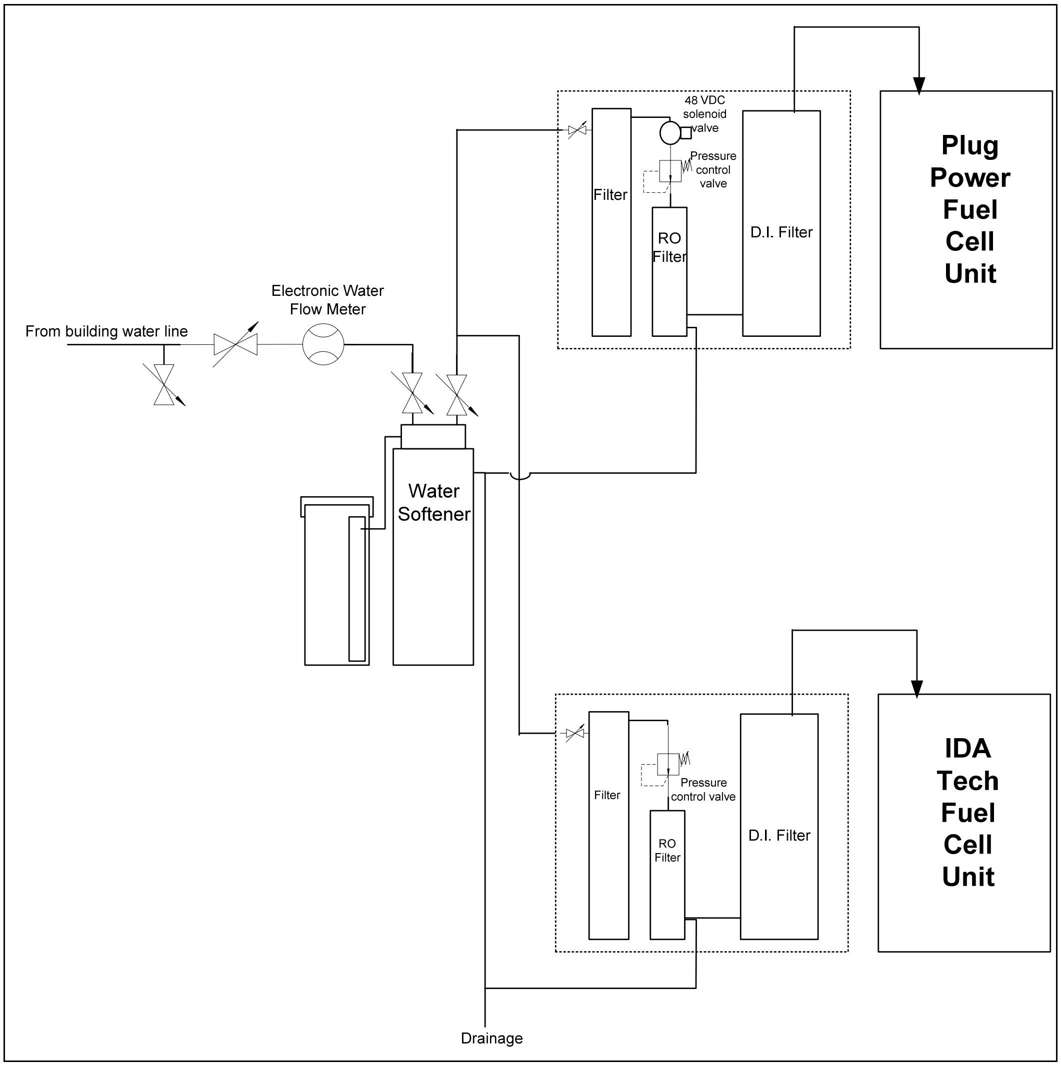


Figure 12-3: A diagram of the water line.

A natural gas line was tapped off of the existing ¾" line at the building. A tee was made inside the boiler room, just before the boiler. The local gas pressure was measured consistently at 7 inches water-column (about 0.25 psig). A minimum of 4 INWC was needed to satisfy both systems' site requirements. A gas line diagram is shown in Figure 12-4.

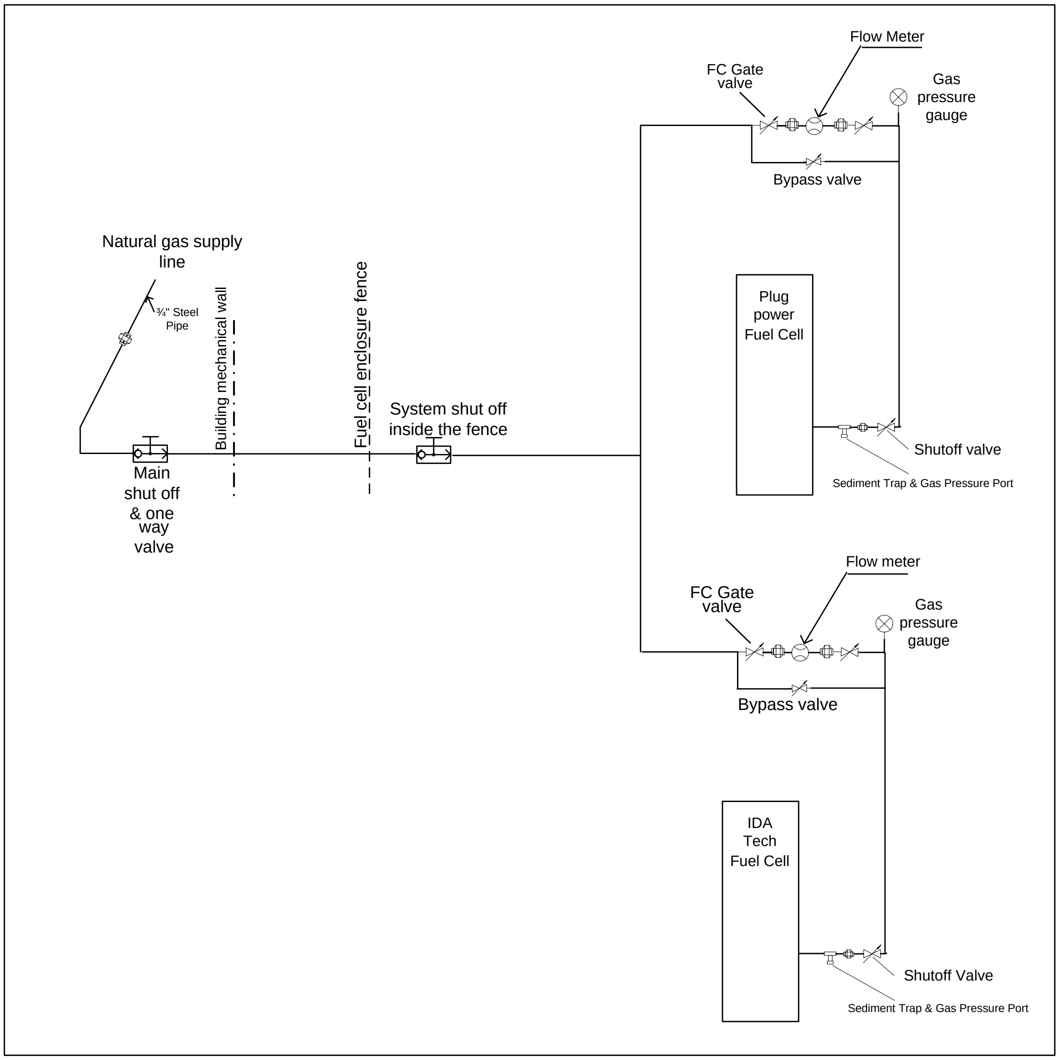


Figure 12-4: A diagram of the natural gas line.

13.0 Installation Costs

The fuel cell site preparation and construction was prepared to handle two systems. An awning was constructed by an outside contractor, but everything else was handled by ASU-PTL, including electric, water, and natural gas lines. A platform was constructed for each fuel cell system. Each platform has a box for data collection. The Plug Power fuel cell platform also holds electrical connection points and grid protection equipment. A list of the site construction costs is shown in Table 13-1.

Item	Company	Total	Purpose
Natural gas flow meters	Alicat Scientific	$1,800	Data Acquisition
Dec LD charges	AT&T	$18	Data Acquisition
ISDN charges	AT&T	$22	Data Acquisition
Watt meter	Davidge Controls	$608	Data Acquisition
Fluid devices	Grainger	$133	Data Acquisition
Power transducers	Jim Gray & Associates	$520	Data Acquisition
Water flow meter	K&P Sales Engineers	$853	Data Acquisition
Water flow rotameter	McMaster-Carr	$39	Data Acquisition
Water flow rotameters	McMaster-Carr	$79	Data Acquisition
Gas meter maintenance	McMillan Company	$150	Data Acquisition
repair meter	McMillan Company	$150	Data Acquisition
200' 4-conductor cable	Mouser	$85	Data Acquisition
2 water meters	Omega Engineering	$368	Data Acquisition
Jan charges	Qwest	$148	Data Acquisition
QWEST ISDN Hookup and 1st Month Service	QWEST	$230	Data Acquisition
Static IP addresses for Internet	QWEST	$434	Data Acquisition
Gas Flow Sensor	R.D. McMillian Company, INC.	$1,450	Data Acquisition
UPS delivery - Omega Engineering	UPS	$42	Data Acquisition
UPS shipment	UPS	$44	Data Acquisition
Twin Fuses Disconnector Switch	Capital Enterprises INC.	$485	Electrical grid connection
Electrical materials	Electric Supply Inc.	$1,140	Electrical grid connection
Electrical materials	Electric Supply Inc.	$98	Electrical grid connection
Electrical materials	Electric Supply Inc.	$22	Electrical grid connection
Electrical parts & accessories	Electric Supply Inc.	$518	Electrical grid connection
electrical control wiring system	Lowe's	$32	Electrical grid connection
IdaTech - Start up training and service	IdaTech	$3,475	IdaTech training
O/U voltage & frequency relays	Basler Electric	$400	Local requirement
Maricopa County Air Quality Permit	Maricopa County	$350	Local requirement
Diamond plate	Davis Salvage Inc.	$995	Platform construction
Cutting wheel	Grainger	$23	Platform construction
Primer and Paint	Grainger	$65	Platform construction
Safety Equipment	Grainger	$188	Platform construction
welding wire and 5/16" SS machine screw	Lowe's	$144	Platform construction
square steel tubings	Davis Salvage	$811	Plumbing
Copper plumbing supplies	Grainger	$319	Plumbing
Water line accessories	Grainger	$28	Plumbing
Water line accessories	Grainger	$13	Plumbing
Water piping and fitting	Lowe's	$92	Plumbing
Water softener and fitting	Lowe's	$483	Plumbing
Brass & copper fittings + tube cutter	McMaster-Carr	$54	Plumbing
Brass fittings	McMaster-Carr	$26	Plumbing
Stainless steel tube fittings	McMaster-Carr	$98	Plumbing
Water Booster Pump	Spectrapure	$263	Plumbing
Awning	Arizona Shade	$1,567	Site awning
Fence surrounding the awning	Lowe's	$408	Site awning
Fence surrounding the awning	Lowe's	$27	Site awning

Table 13-1: Fuel cell site installation costs.

14.0 Acceptance Test

Acceptance tests of the two fuel cell systems were conducted at their respective manufacturing sites. In addition ASU-PTL conducted its own acceptance test of its own external data acquisition system. Because ASU-PTL has access to the Plug Power internal data, a comparison could be made to validate the Plug Power reported data with ASU-PTL's own externally collected data.

A simple cross-check was made after 3.5 months of operation. Taking a look at the overall data collected, the largest discrepancy came from the natural gas consumption. The Plug Power onboard computer (SARC) reported less natural gas consumption than ASU-PTL measured. In this Gensys model, the natural gas flow meter was removed by Plug Power, who estimated the natural gas flow through an algorithm based on other system parameters. ASU-PTL measured natural gas flow directly from a meter external to the system. This variation in data collection may explain some of the discrepancy in the natural gas consumption data, along with uncertainty of the equipment used.

	Plug Power	ASU-PTL	% difference {(ASUPTL-PlugPower) /ASUPTL}
Run Time (hours)	2,596	2,594	-0.08%
Period Time (hours)	2,700	2,700	0.00%
Simple Availability (%)	96.16	96.09	-0.08%
Energy Produced (kWh)	6,508	6,526	0.28%
Average Power (kW)	2.51	2.52	0.36%
Gas Consumed (cu ft)	88,141	95,001	7.22%
Energy Consumed (Therms)	905	976	7.22%
Electrical Efficiency (%)	24.53	22.82	-7.48%

Table 14-1: Data cross-check of Plug Power reported data and ASU-PTL measured data.

Appendix 1 Initial Monthly Performance Data

Format for PEM Fuel Cell Performance Data

System Number: nGen5 - 0083E
Site Name: Sylvestre S. Herrera
Fuel Type: Natural Gas
Low Heating Value: 1,027 Btu/cu ft
Capacity kW 4.5

Commission Date: 4/14/2005
Fuel Cell Type: PEM
Maintenance Contractor: ASU-PTL
Local Residential Fuel Cost per Therm: 1.00787 $/Therm
Local Residential Electricity Cost per kWhr: 0.0907 $/kWhr

Site Location(City,State): Mesa, AZ
Local Base Fuel Cost per Therm: 0.78876 $/Therm
Local Base Electricity Cost per kWhr: 0.0423 $/kWhr

Month	Run Time (Hours)	Time in Period (Hours)	Availability (%)	Energy Produced (kWe-hrs AC)	Output Setting (kW)	Average Output (kW)	Capacity Factor (%)	Fuel Usage, LHV (BTUs)	Fuel Usage (SCF)	Electrical Efficiency (%)	Thermal Heat Recovery (BTUs)	Heat Recovery Rate (BTUs/hour)	Thermal Efficiency (%)	Overall Efficiency (%)	Number of Scheduled Outages	Scheduled Outage Hours	Number of Unscheduled Outages	Unscheduled Outage Hours
insert month	*insert operating hours*	*insert hours in month*	*1	*insert produced energy*	*insert output setting*	*2	*3	*insert fuel consumption*	*insert fuel consumption*	*4	*insert heat recovery*	*5	*6	*7	*insert value*	*insert value*	*insert value*	*insert value*
April-05	388.2	388.9	100%	768.68	2	1.98	43.92%	1.11E+07	10819	23.62%	0	0	0.00%	23.62%	1	0.7	0	0
May-05	515.9	744	69%	1023.31	2	1.98	30.56%	1.45E+07	14124	24.09%	0	0	0.00%	24.09%	0	0	3	228.1
June-05	458.7	720	64%	823.68	2.3	1.80	25.42%	1.08E+07	10550	25.95%	0	0	0.00%	25.95%	0	0	6	261.3
July-05	494.4	744	66%	963.57	2.3	1.95	28.78%	1.13E+07	11028	29.04%	0	0	0.00%	29.04%	1	1.1	6	248.5
Running Totals																		
	Total Run Time	Total Hours in Period	Total Availability (*8)	Total Energy Produced	Average Output Setting	Total Average Output (*9)	Total Capacity Factor (*10)	Total Fuel Usage	Total Fuel Usage	Average Electrical Efficiency (*11)	Total Thermal Heat Recovery	Average Heat Recovery Rate (*12)	Average Thermal Efficiency (*13)	Average Overall Efficiency (*14)	Total Outages	Total Hours	Total Outages	Total Hours
	1,857	2,597	72%	3,579	2.15	1.93	30.63%	4.78E+07	46,521	25.58%	0	0	0.00%	25.58%	2	1.8	15	737.9

Format for PEM Fuel Cell Performance Data

System Number: Gensys 5C - B285
Site Name: Sylvestre S. Herrera
Fuel Type: Natural Gas
Low Heating Value: 1,027 Btu/cu ft
Capacity kW 5

Commission Date: 3/25/2005
Fuel Cell Type: PEM
Maintenance Contractor: ASU-PTL
Local Residential Fuel Cost per Therm: 1.00787 $/Therm
Local Residential Electricity Cost per kWhr: 0.0907 $/kWhr

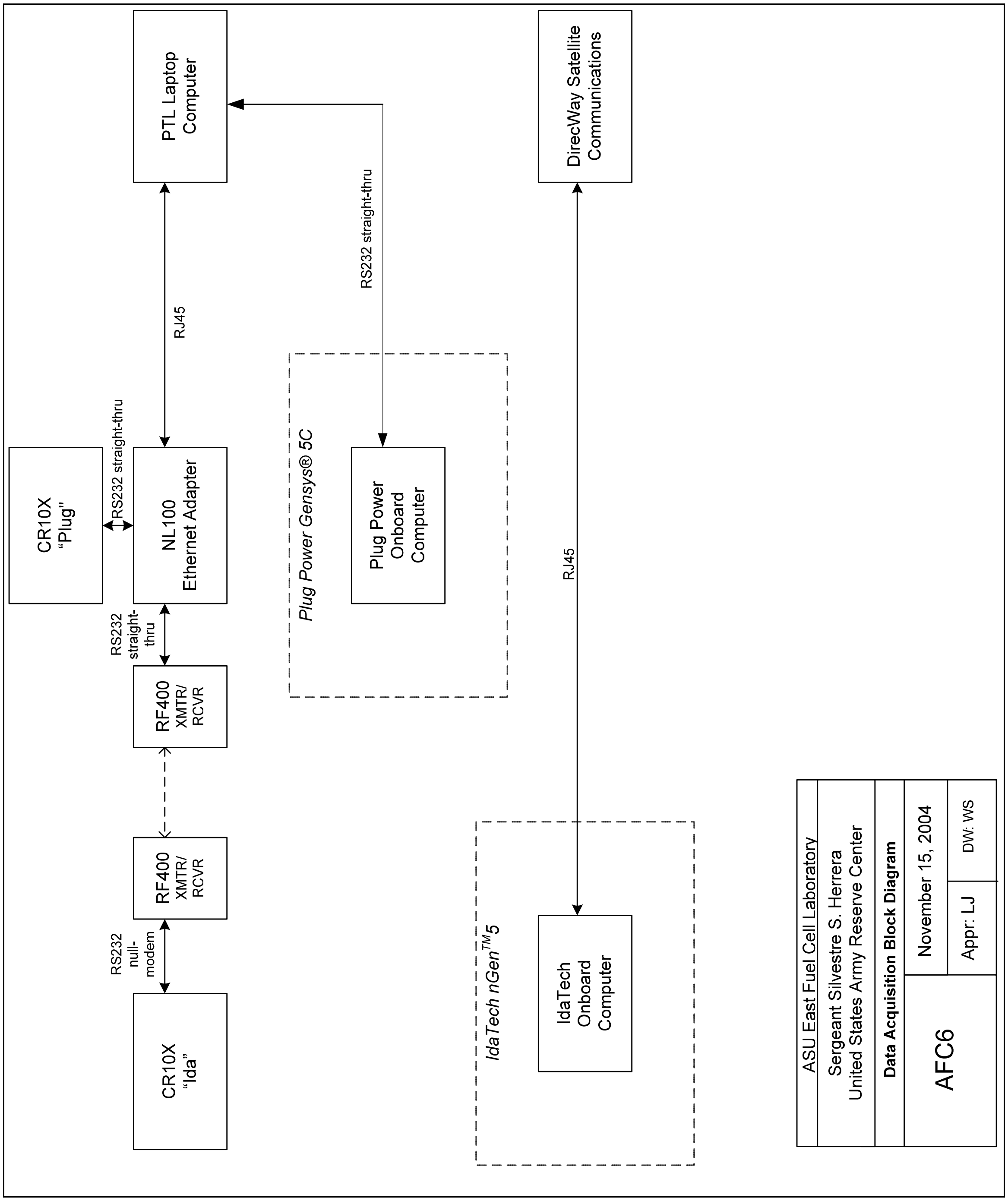
Site Location(City,State): Mesa, AZ
Local Base Fuel Cost per Therm: 0.78876 $/Therm
Local Base Electricity Cost per kWhr: 0.0423 $/kWhr

Month	Run Time (Hours)	Time in Period (Hours)	Availability (%)	Energy Produced (kWe-hrs AC)	Output Setting (kW)	Average Output (kW)	Capacity Factor (%)	Fuel Usage, LHV (BTUs)	Fuel Usage (SCF)	Electrical Efficiency (%)	Thermal Heat Recovery (BTUs)	Heat Recovery Rate (BTUs/hour)	Thermal Efficiency (%)	Overall Efficiency (%)	Number of Scheduled Outages	Scheduled Outage Hours	Number of Unscheduled Outages	Unscheduled Outage Hours
insert month	*insert operating hours*	*insert hours in month*	*1	*insert produced energy*	*insert output setting*	*2	*3	*insert fuel consumption*	*insert fuel consumption*	*4	*insert heat recovery*	*5	*6	*7	*insert value*	*insert value*	*insert value*	*insert value*
March-05	130	156	83%	325	2.5	2.51	41.69%	4.45E+06	4,336	24.93%	0	0	0.00%	24.93%	0	0	1	26.25
April-05	659	720	92%	1,643	2.5	2.49	45.65%	2.21E+07	21,738	25.40%	0	0	0.00%	25.40%	0	0	1	60.737
May-05	729	744	98%	1,815	2.5	2.49	48.79%	2.80E+07	27,280	22.12%	0	0	0.00%	22.12%	0	0	4	15.4
June-05	717	720	100%	1,808	2.5	2.52	50.22%	2.89E+07	28,175	21.33%	0	0	0.00%	21.33%	0	0	7	3.1
July-05	744	744	100%	1,876	2.5	2.52	50.43%	2.78E+07	27,047	23.06%	0	0	0.00%	23.06%	0	0	2	0.2
Running Totals																		
	Total Run Time	Total Hours in Period	Total Availability (*8)	Total Energy Produced	Average Output Setting	Total Average Output (*9)	Total Capacity Factor (*10)	Total Fuel Usage	Total Fuel Usage	Average Electrical Efficiency (*11)	Total Thermal Heat Recovery	Average Heat Recovery Rate (*12)	Average Thermal Efficiency (*13)	Average Overall Efficiency (*14)	Total Outages	Total Hours	Total Outages	Total Hours
	2,979	3,084	97%	7,468	2.50	2.51	48.43%	1.11E+08	108,576	22.91%	0	0	0.00%	22.91%	0	0	15	105.7

Appendix 2 Documentation of Acceptance Test

Documentation of acceptance testing by each manufacturer should be provided to CERL by the respective fuel cell manufacturers.

Appendix 3 Additional Relevant Documents



Fuel Cell Events Log

Date	Time	System	Event/Comment	Event Code	Scheduled/ Unscheduled	Hours Down
3/25/05	12:00	Plug Power	System initial startup.	START	SCH	0
3/30/05	12:39	Plug Power	Unscheduled outage. DI water solenoid fuse blown. Fuse F57 on the SARC board.	E	UNSCH	26.25
4/6/05	6:34	Plug Power	Unscheduled outage. DI water solenoid fuse blown. Fuse F57 on the SARC board.	E	UNSCH	1.367
4/14/05	19:00	IdaTech	System initial startup.	START	SCH	0
4/17/05	5:00	Plug Power	Unschedule outage. Bad relay (K3) to CPO heater (HR2).	E	UNSCH	60
4/19/05	17:00	Plug Power	System restarted and back up into steady state operation.	START	SCH	0
5/12/05		Plug Power	Installed Alicat Scientific gas meter	LAB	SCH	0
5/13/05		IdaTech	Installed Alicat Scientific gas meter	LAB	SCH	0
5/13/05	11:54	IdaTech	Unscheduled outage. Low gas pressure due to new meter.	LAB	UNSCH	0.5
5/20/05	9:24	Plug Power	Unsheduled outage. No clear cause.	UNKWN	UNSCH	4
5/21/05	15:00	IdaTech	Unscheduled outage. Flame burnout	REF	UNSCH	127.7
5/27/05	7:18	Plug Power	Unscheduled outage. Low Battery	BAT	UNSCH	10.3
5/27/05	20:06	IdaTech	Unscheduled outage. Flame burnout	REF	UNSCH	99.9
6/3/05	20:35	Both	Loss of grid	GRID	UNSCH	0.18
6/5/05	2:50	Plug Power	Loss of grid	GRID	UNSCH	0.1
6/5/05	3:00	IdaTech	Power down for reformer and stack replacement. Also replaced desulphurization bed and water filters.	FC	UNSCH	109.9
6/11/05	7:18	IdaTech	Loss of grid	GRID	UNSCH	51
6/11/05	7:18	Plug Power	Loss of grid	GRID	UNSCH	1.7
6/12/05	8:48	Plug Power	Loss of grid	UNKWN	UNSCH	0.3
6/14/05	21:48	Plug Power	Loss of grid	GRID	UNSCH	0.2
6/14/05	21:48	IdaTech	Loss of grid	GRID	UNSCH	13.2
6/20/05	22:30	IdaTech	Water - temperature problems	FC	UNSCH	35.1
6/22/05	10:36	IdaTech	Water flow meter clogged	H2O	UNSCH	37
6/23/05	20:48	Plug Power	Loss of grid	GRID	UNSCH	0.2
6/23/05	22:12	Plug Power	Loss of grid	GRID	UNSCH	0.4
7/2/05	13:12	IdaTech	Cogen cooling fan not running. Fan motor bad. Replaced.	BOP	UNSCH	119.6
7/11/05	10:18	IdaTech	Replaced coolant with distilled water.	BOP	SCH	1.1
7/11/05	17:06	IdaTech	Loss of grid	GRID	UNSCH	15.9
7/11/05	17:06	Plug Power	Loss of grid	GRID	UNSCH	0.1
7/12/05	16:00	IdaTech	Cogen/cabinet temperature too high	BOP	UNSCH	15.8
7/13/05	14:42	IdaTech	Cogen/cabinet temperature too high	BOP	UNSCH	16.7
7/17/05	14:54	IdaTech	Cogen/cabinet temperature too high	BOP	UNSCH	17.8
7/22/05	20:48	IdaTech	Loss of grid	GRID	UNSCH	60.9
7/22/05	20:48	Plug Power	Loss of grid	GRID	UNSCH	0.1

SOUTHWEST GAS CORPORATION
P.O. Box 98510
Las Vegas, Nevada 89193-8510
Arizona Gas Tariff No. 7 — Sixty-Ninth Revised A.C.C. Sheet No. 12
Arizona Division — Canceling Sixty-Eighth Revised A.C.C. Sheet No. 12

STATEMENT OF RATES

EFFECTIVE SALES RATES APPLICABLE TO ARIZONA SCHEDULES [1/]

(Continued)

Description	Base Tariff Rate: Margin	Base Tariff Rate: Gas Cost	2/ Rate Adjustment	Monthly Gas Cost Adjustment	Currently Effective Tariff Rate	
G-30 – Optional Gas Serivce						
Basic Service Charge per Month	As specified on A.C.C. Sheet No. 27.					
Commodity Charge per Therm:						
All Usage	As specified on A.C.C. Sheet No. 28.					
G-35 – Gas Service to Armed Forces						
Basic Service Charge per Month	$350.00				$350.00	
Commodity Charge per Therm:						
All Usage	$ .18966	$ .37034	$ .02000	$ .23559	$ .81559	I
G-40 – Air-Conditioning Gas Service						
Basic Service Charge per Month	As specified on A.C.C. Sheet No. 32.					
Commodity Charge per Therm:						
All Usage	$ .07613	$ .37034	$ .02000	$ .23559	$ .70206	I
G-45 – Street Lighting Gas Service						
Commodity Charge per Therm of Rated Capacity:						
All Usage	$ .47648	$ .37034	$ .02000	$ .23559	$ 1.10241	I
G-55 – Gas Service for Compression on Customer's Premises 5/						
Basic Service Charge per Month:						
Small	$ 20.00				$ 20.00	
Large	170.00				170.00	
Residential	8.00				8.00	
Commodity Charge per Therm:						
Small, All Usage	$ .13305	$ .37034	$ .02000	$ .23559	$ .75898	I
Large, All Usage	.13305	.37034	.02000	.23559	.75898	I
G-60 – Cogeneration Gas Service 4/						
Basic Service Charge per Month	As specified on A.C.C. Sheet No. 40.					
Commodity Charge per Therm:						
All Usage	$ .08934	$ .55840			$ .64774	
G-75 – Small Essential Agricultural User Gas Service						
Basic Service Charge per Month	$ 75.00				$ 75.00	
Commodity Charge per Therm:						
All Usage	$ .19468	$ .37034	$ .02000	$ .23559	$ .82061	I
G-80 – Natural Gas Engine Gas Service 4/						
Basic Service Charge per Month:						
Off-Peak Season (October–March)	$ 0.00				$ 0.00	
Peak Season (April–September)	80.00				$ 80.00	
Commodity Charge per Therm:						
All Usage	$ .16189	$. 55840			$ .72029	

Issued On May 23, 2005
Docket No. G-00000C-98-0568

Issued by
John P. Hester
Vice President

Effective May 31, 2005
Decision No. 62994

E-36
Page 2
Published: 11/1/2005

	Summer* May - October	Winter* November – April
Per kW Charges (all kW over 5 kW)		
Distribution Delivery	$1.03	$0.76
Transmission Delivery	$2.55	$1.09
Ancillary Services 1-2	$0.07	$0.03
Total	$3.65	$1.88

	Summer * May - October	Winter* November – April
Per kWh Charge		
First 350 kWh:		
Distribution Delivery	$0.0211	$0.0138
Transmission Delivery	$0.0048	$0.0046
Ancillary Services 1-2	$0.0005	$0.0004
Ancillary Services 3-6	$0.0006	$0.0006
System Benefits	$0.0019	$0.0019
Competitive Customer Service	$0.0028	$0.0027
Energy	$0.0240	$0.0177
Fuel and Purchased Power †	$0.0257	$0.0223
Total	$0.0814	$0.0640
Next 180 kWh per kW of billing demand or, if no billing demand, all remaining kWh:		
Distribution Delivery	$0.0211	$0.0138
Transmission Delivery	$0.0048	$0.0046
Ancillary Services 1-2	$0.0005	$0.0004
Ancillary Services 3-6	$0.0006	$0.0006
System Benefits	$0.0019	$0.0019
Competitive Customer Service	$0.0028	$0.0027
Energy	$0.0240	$0.0177
Fuel and Purchased Power †	$0.0257	$0.0223
Total	$0.0814	$0.0640